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STATION PAPER NO. 149 • NORTHEASTERN FOREST EXPERIMENT STATION • 1960

U.S. FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE • UPPER DARBY, PA.

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JESSE D. DILLER, a plant pathologist, has worked for many years on projects to prevent and control decay in structural timbers. He has also done extensive research to select and test blight-resistant American chestnuts. He was graduated from Bluffton College (1924) with an A.B. degree, Ohio State University (1926) with an A.M. degree, and Yale University with M.F. (1930) and Ph.D. (1940) degrees. During the 1920's he worked 2 years in Liberia, West Africa, on a Firestone rubber plantation. Upon his return, he joined the U. S. Department of Agriculture, eventually coming with the Bureau of Plant Industry and finally in 1954 with the Forest Service. He is now on the staff of the Laurel Research Center in Maryland.

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THE TWO building decay fungi, the European *Merulius lacrymans* Fr. and the native *Poria incrassata* (Berk. & Curt.) Burt., do not often become established in buildings. But when they do, these fungi can cause serious damage to structural timbers. In extreme cases they have advanced to the second and third floor of buildings. This is possible because of their special ability to conduct water from the soil to the point of attack.

No work has been reported that shows why these fungi can at times cause such serious damage when ordinarily their activity is rather restricted. It has been felt that some environmental condition may be responsible for the variation in advances by these fungi. If it were found that certain substrata environments favor their growth, this knowledge could be useful in designing control practices.

With these thoughts in mind the authors set out to design an experiment:

o To determine the response of *Merulius lacrymans* when grown on sand, soil and limed soil, and to determine the influence on fungus growth of three fertilizer materials added to these substrata.

o To compare the developments of *M. lacrymans* in the environment where it is often found (in the crawl space of an occupied house) with an abandoned root cellar, with a forested area, and with an environment having controlled temperature and relative humidity. The percent weight loss of 13 wood species, each represented with three classes of wood --sapwood, mixed heartwood and sapwood, and heartwood--were used in assessing the influence of the factors stated above.

Material and Methods

A factorial experiment was begun in July 1955. A total of 288 eight-ounce cans were collected and the tops partially cut to provide a hinged lid. Neutral, white inert sand was placed to a depth of 1 inch in 96 of the cans. Fine Chester loam having a 5.8 pH reaction was placed to a depth of 1 inch in another 96 cans. The same fine Chester loam, conditioned to a pH reaction of 7.2 by the addition of finely ground limestone, was placed to a depth of 1 inch in the remaining 96 cans.[1]

Of each of the three groups of cans, one-fourth were left untreated. Ammonium sulphate (acid reaction) fertilizer was added to a fourth of the cans. Bonemeal (neutral reaction) was added to another fourth of the cans, and nitrate of soda (basic reaction) was added to the remaining fourth. In every case the fertilizers were applied at the rate of 200 pounds per acre, a rate that a householder might use in a flower bed along the foundation wall of his dwelling.

The following wood species were used in this experiment:

Baldcypress	- *Taxodium distichum* (L.) Rich.
Black (shipmast) locust	- *Robinia pseudoacacia* L.
Chinese chestnut	- *Castanea mollissima* Blume
Douglas-fir	- *Pseudotsuga menziesii* (Mirb.) Franco
Eastern hemlock	- *Tsuga canadensis* (L.) Carr.
Eastern redcedar	- *Juniperus virginiana* Mill.
Japanese chestnut	- *Castanea crenata* Sieb. Zucc.
Mahogany	- *Swietenia macrophylla* King

[1] Conditioned soils were furnished by the Soil and Water Conservation Research Division of the Agricultural Research Service.

Northern red oak - *Quercus rubra* L.
Osage-orange - *Maclura pomifera* (Raf.) Schmeid.
Teak - *Tectona grandis* L.F.
Virginia pine - *Pinus virginiana* Mill.
White mulberry - *Morus alba* L.

One hundred forty-four blocks of each species were cut, measuring approximately 1 x 2 x 8 centimeters. Individual weights were recorded to the nearest .01 gram. For each species 48 or one-third of the blocks were sapwood only, 48 were heartwood, and 48 had some sapwood and some heartwood (henceforth designated as heart-sapwood). The first 6 species mentioned above were distributed to 144 of the cans and the last 7 species were distributed to the other 144 cans. (These small cans would accommodate only 7 wood blocks.) Each can thus contained only 1 class of wood, 1 fertilizer, 1 substratum and either 6 or 7 different wood species.

After placing the wood blocks in the cans, each can was inoculated artificially by introducing small wood chips infected with the fungus *Merulius lacrymans;* then 50 cc. of tap water was added to each can. In a previous study involving *M. lacrymans* and *P. incrassata,*[2] *Merulius* was found to be consistently more destructive on 23 wood species and the two fungi showed very little interaction with species. For these reasons it was felt that this study could be limited to *Merulius.*

A set containing 72 cans representing all combinations of the factorial were placed in each of the following four environments in or near the Plant Industry Station, Beltsville, Maryland, in July 1955:

- In the crawl space of a basementless, frame duplex dwelling.

- Under a mound of forest leaves in a wooded area.

- In an abandoned root cellar having high relative humidity.

- In a room with the temperature controlled at 40°F.

During the course of the experiment small amounts of water were added to the cans when needed. After 2 years the

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[2]Diller, J. D., and Koch, E. J. Weight losses of 40 wood species exposed to Poria Incrassata and Merulius Lacrymans. Forest Prod. Jour. 9: 298-302, illus. 1959.

blocks were removed, air-dried to 8 to 10 percent, and weighed; and the percent weight loss of each block was determined. Analyses of variance were run on each species.

Experimental Results

The influence of substrata on weight loss is shown in table 1. For all 13 species, the blocks placed on sand averaged 6.0 percent weight loss, those placed on acid soil (initial pH 5.8) averaged 8.5 percent weight loss, and those placed on basic soil (initial pH 7.2) averaged 8.7 percent weight loss. The influence of substrata appears to be more pronounced for the three species with the most weight loss--northern red oak, Virginia pine and eastern hemlock--than it does for the 10 other species. In only black locust does there appear to be any association with initial pH of the substratum.

Table 2 shows the effect on weight loss when fertilizer is added to the substratum. The average weight losses for no fertilizer (the check) was 8.1 percent; for ammonium sulphate 8.3 percent; for bonemeal 7.1 percent; and for nitrate of soda 7.4 percent.

Table 1.--Effect of 3 substrata on the percent of weight loss of 13 wood species after 2 years exposure Merulius lacrymans

Wood species	Substrata		
	Sand (neutral)	Acid soil	Basic soil
Northern red oak	[1] 11.2a	19.5b	19.3b
Eastern hemlock	9.8a	13.1ab	15.5b
Virginia pine	7.4a	13.5b	14.0b
Chinese chestnut	9.3a	10.0a	9.9a
Japanese chestnut	6.5a	8.6ab	10.1b
Eastern redcedar	6.3a	8.1ab	8.7b
White mulberry	6.4a	8.2b	7.9b
Black locust	6.2a	5.7a	7.0a
Mahogany	4.0a	6.9b	7.0b
Teak	4.2a	4.6a	4.5a
Douglas-fir	2.2a	5.1b	4.0b
Baldcypress	2.5a	5.0b	3.2a
Osage-orange	1.7a	1.9a	2.1a
Average	6.0	8.5	8.7

[1] Means for the same species which are not followed by the same letter are significantly different at the 5 percent level.

Test results (table 3) show that environments played an important role in relation to weight loss. The average weight loss for the 13 species stored in the 40°F. constant-temperature environment was only 3.7 percent in comparison to a weight loss of 11.1 percent for the 468 blocks stored in the crawl-space area. The weight loss averaged 7.4 percent for those in the root cellar and 8.8 percent for the blocks stored beneath mounds of leaves under forest conditions. With few exceptions this general pattern held for all 13 species.

The relative weight losses of the 13 wood species are presented in table 4. In this test, Osage-orange, baldcypress, Douglas-fir and teak averaged less than 5 percent weight loss while Virginia pine, eastern hemlock, and northern red oak averaged more than 10 percent. The average for the 13 species was 7.7 percent, with a weight loss average of 6.4 percent for heartwood, 7.7 percent for heart-sapwood, and 9.1 percent for sapwood. The difference in percent weight loss for the different classes of woods was small for northern red oak, eastern hemlock, Chinese chestnut, black locust, Douglas-fir, and Osage-orange. However, Virginia pine sapwood lost nearly three times as much as heartwood and white mulberry sapwood lost more than 3.5 times as much weight as heartwood. The rest of the species show trends similar but less pronounced.

Discussion of Results

From the results (table 1) we concluded that the difference between sand and soil as substrata was much more important than the initial pH reaction of the substrata. Sand resulted in the least weight loss for all species except black locust. For six species the greatest weight loss occurred with acid substrata and for the remaining seven species the greatest weight loss occurred with basic substrata.

The failure of the various fertilizer additives to consistently affect the development of *M. lacrymans* indicates that these additives to the substrata exerted little or no influence on the fungus.

The most striking result of this study was the effect of environment on percent weight loss. For every species the weight loss was less in the 40°F. constant temperature room, and often considerably less. This may indicate either

Table 2.--Effect of adding fertilizer to the substrata on the percent of weight loss of 13 wood species after 2 years exposure to *Merulius lacrymans*

Wood species	Fertilizers			
	No additives (check)	Acid: ammonium sulphate	Neutral: bonemeal	Basic: nitrate of soda
Northern red oak	[1]15.8a	18.1a	15.9a	16.8a
Eastern hemlock	13.6a	12.1a	12.0a	13.5a
Virginia pine	12.0ab	13.9b	9.9a	10.9ab
Chinese chestnut	10.1a	9.6a	9.7a	9.7a
Japanese chestnut	10.4b	9.2b	6.0a	8.1ab
Eastern redcedar	8.8a	8.3a	6.9a	6.9a
White mulberry	7.6a	8.2a	7.3a	7.0a
Black locust	5.7a	7.4a	5.7a	6.3a
Mahogany	6.5a	6.1a	5.6a	5.7a
Teak	4.6ab	4.9b	4.3ab	3.9a
Douglas-fir	4.3b	4.8b	3.6ab	2.4a
Baldcypress	3.7a	2.9a	3.7a	4.0a
Osage-orange	2.0a	2.1a	1.8a	1.6a
Average	8.1	8.3	7.1	7.4

[1]Means for the same species which are not followed by the same letter are significantly different at the 5 percent level.

Table 3.--Effect of environmental conditions on percent of weight loss of 13 wood species after 2 years exposure to *Merulius lacrymans*

Wood species	Environment				Average
	Constant temperature	Root cellar	Forest conditions	Crawl space	
Northern red oak	[1]8.4a	17.2b	20.7c	20.3c	16.7
Eastern hemlock	6.3a	11.8b	14.0b	19.0c	12.8
Virginia pine	5.1a	11.5b	14.0bc	16.1c	11.7
Chinese chestnut	6.7a	10.6bc	9.8b	11.8c	9.8
Japanese chestnut	2.9a	9.3b	8.4b	13.0c	8.4
Eastern redcedar	3.6a	5.9b	8.8c	12.5d	7.7
White mulberry	4.3a	8.9b	7.8b	9.1b	7.5
Black locust	4.1a	4.3a	7.6b	9.1b	6.3
Mahogany	1.4a	4.4b	6.6b	11.5c	6.0
Teak	3.4a	3.9a	4.9b	5.5b	4.4
Douglas-fir	- .1a	2.6b	4.6c	7.8d	3.7
Baldcypress	.9a	3.4b	4.0b	5.9c	3.6
Osage-orange	.9a	2.3bc	2.6bc	1.8b	1.9
Average	3.7	7.4	8.8	11.1	7.7

[1]Means for the same species which are not followed by the same letter are significantly different at the 5 percent level.

that 40°F. is an unsatisfactory temperature for growth of the fungus or that a variable temperature is more conductive to active growth than a constant temperature.

For Douglas-fir there was a slight and insignificant gain in weight over a 2-year period for the blocks stored in this constant-temperature environment. This gain in weight was associated mostly with the blocks placed on sand. For all species except Osage-orange, the greatest percent weight loss occurred in the crawl space of a basementless house. The weight loss for the blocks stored in the root cellar and under forest conditions was intermediate, and differences between them were not consistent for the various species. Data for the most natural conditions--under a mound of forest leaves--was intermediate and may explain why the fungus is seldom found in forests.

Of the 13 species tested, Osage-orange showed the least weight loss, as was also found in a previous study.[2] However, eastern redcedar and Japanese chestnut, which showed moderate weight losses in this study, both showed small weight losses in the previous study. Particularly the heartwood of eastern redcedar showed more weight loss than was

Table 4.--Comparison of percent of weight loss of heartwood, heart-sapwood, and sapwood of 13 wood species after 2 years exposure to *Merulius lacrymans*

Wood species	Class of wood			Average
	Heartwood	Heart-sapwood	Sapwood	
Northern red oak	[1]15.5a	17.7a	16.8a	16.7
Eastern hemlock	12.3a	14.4a	11.7a	12.8
Virginia pine	5.7a	12.3b	16.9c	11.7
Chinese chestnut	9.6a	9.6a	10.1a	9.8
Japanese chestnut	6.7a	9.2b	9.3b	8.4
Eastern redcedar	6.3a	7.0a	9.8b	7.7
White mulberry	3.9a	4.1a	14.6b	7.5
Black locust	6.3a	5.7a	6.9a	6.3
Mahogany	5.0a	6.1a	6.9a	6.0
Teak	3.4a	4.0a	5.8b	4.4
Douglas-fir	3.7a	3.9a	3.7a	3.7
Baldcypress	2.4a	4.5b	3.8b	3.6
Osage-orange	1.9ab	1.5a	2.2b	1.9
Average	6.4	7.7	9.1	7.7

[1]Means for the same species which are not followed by the same letter are significantly different at the 5 percent level.

expected from the previous work. Douglas-fir and baldcypress, which had less than 5 percent weight loss in the present study, previously showed rather heavy weight losses. These differences in results between the two studies may be due to the particular pieces of wood from which blocks were obtained.

As a check on the final pH of the substrata at the end of the study, the pH of each can was determined by means of a Beckman pH meter. Without exception these readings indicated that the pH was lower at the end of the experiment than at the beginning. The average pH for all cans was 5.3. The acid substratum had an average pH of 4.9, the sand a pH of 5.0, and the basic substratum a pH of 6.2. There was a slight overall trend with class of wood. The pH of the heartwood substrata averaged 5.2, heart-sapwood substrata averaged 5.3, and sapwood substrata averaged 5.4.

The addition of fertilizers did not result in the expected influence on substrata to pH. The substrata in cans without fertilizer had an average pH value of 5.3, the acid fertilizer (ammonium sulphate) averaged 5.5, the neutral fertilizer (bonemeal) averaged 5.1, and the basic fertilizer (nitrate of soda) 5.3.

The pH of the substrata was not correlated with the weight-loss values as far as environment was concerned. The average pH in the crawl space and in the 40°F. room were both 5.5. The pH of the substrata in the cans stored under a mound of leaves averaged 5.3, and in the root cellar pH averaged 5.1. Since conditioning of the substrata soil at the beginning of the experiment to a specified pH was not permanent, no valid conclusions can be made as to the influence of substrata pH on the development of *M. lacrymans*. It has been shown, however, that the pH of soil fertilizers will not change the pH of the substrata appreciably, and that attempts to alter the pH of the substrata by the addition of finely ground limestone were not successful.

Summary

An experiment was conducted to determine whether substrata, fertilizers, environments, and wood species affect the development of *Merulius lacrymans* as measured by percent weight loss of wood blocks after 2 years of exposure. The pH of the substrata was found to have little correlation with percent weight loss. However, the difference between sand and soil was appreciable. The pH of the soil fertilizer

was not correlated with percent weight loss. Of the three fertilizers, bonemeal produced the least percent weight loss. Response to fertilizer was quite different for various wood species. Of the four environments, the 40°F. constant temperature resulted in the least weight loss and the crawl space of a basementless house resulted in the most weight loss. Overall the average weight loss for the 13 species ranged from 1.9 percent for Osage-orange to 16.7 percent for northern red oak. As for class of wood, percent weight loss was 6.4 percent for heartwood, 7.7 percent for heart-sapwood, and 9.1 percent for sapwood. The authors conclude that no pH effect was demonstrated, but the factors--environment, species, and substrata material--influenced the development of the fungus.